Real-Time Very High-Resolution Regional 4D Assimilation in Supporting CRYSTAL-FACE Experimrnt

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Title of Research Grant: Real-Time Very High-Resolution Regional 4D Assimilation in Supporting NASA CRYSTAL-FACE Experiment
Grant Number: NAG5-11477
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August 2004

1. Real-Time Forecast Support for CRYSTAL-FACE Mission

To better understand tropical cirrus cloud physical properties and formation processes with a view toward the successful modeling of the Earth's climate, the CRYSTAL-FACE (Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment) field experiment took place over southern Florida from 1 July to 29 July 2002. During the entire field campaign, a very high-resolution numerical weather prediction (NWP) and assimilation system was performed in support of the mission with supercomputing resources provided by NASA Center for Computational Sciences (NCCS).

By using NOAA NCEP Eta forecast for boundary conditions and as a first guess for initial conditions assimilated with all available observations, two nested 15/3 km grids (Fig. 1) are employed over the CRYSTAL-FACE experiment area. The 15-km grid covers the southeast US domain, and is run two times daily for a 36-hour forecast starting at 0000 UTC and 1200 UTC. The nested 3-km grid covering only southern Florida is used for 9-hour and 18-hour forecasts starting at 1500 and 0600 UTC, respectively.

The forecasting system provided more accurate and higher spatial and temporal resolution forecasts of 4-D atmospheric fields over the experiment area than available from standard weather forecast models. These forecasts were essential for flight planning during both the afternoon prior to a flight day and the morning of a flight day. The forecasts were used to help decide takeoff times and the most optimal flight areas for accomplishing the mission objectives. See more detailed products on the web site http://asd-www.larc.nasa.gov/model/crystal (Fig. 2).

The model/assimilation output gridded data are archived on the NASA Center for Computational Sciences (NCCS) UniTree system in the HDF format at 30-min intervals for real-time forecasts or 5-min intervals for the post-mission case studies. Particularly, the data set includes the 3-D cloud fields (cloud liquid water, rain water, cloud ice, snow and graupel/hail).

2. Continuing High-Resolution Assimilated Gridded-Data Support for the Community

For some selected target observation cases, the enhancements to the assimilated data set have being made through utilizing additional Mission-observed data sources. We have been examining the use of the extensive experiment measurements, especially the radar data, satellite data and aircraft data as well as NWS/PARSL/Mobile radiosondes/dropsondes, in the higher-resolution 4D data assimilation for some interesting cases. This high spatial and temporal resolution data set has being customized to initialize other numerical models/simulations, including cloud system modeling, large eddy simulation (LES), and the aerosol/trace dispersion simulation as well as the small-scale chemical transport modeling. It is successfully being used by the research groups listed below:

a) Ames' cloud-related modeling group uses the model data to drive the particle size resolving model, the results have been published in *SCIENCE*. The PI is a coauthor.

b) David Starr's group at GSFC uses the dataset to compare with MM5 model results and to their cirrus bin-microphysics modeling.

c) Ken Pickering at University of Maryland uses the model output to drive a cloud scale chemical transport model.

d) Vitaly Khvorostyanov (in Russia) and Judy Curry use the model data for their bin model to study thin cirrus clouds.

e) Ping Yang at Texas A&M and Yongxiang Hu at NASA Langley are trying to use the model cirrus data for remote sensing and radiative transfer studies.

f) Jay Mace at the University of Utah would like to use the model data to compare with ground-based measurements.

3. Continuing Convection-Anvil and Thin-Cirrus Simulations

We conducted convection-anvil cloud system simulations and thin-cirrus modeling during CRYSTAL-FACE, to attempt to (1) examine the formation and evolution of these cloud systems and their interaction and feedback processes with radiation, microphysics, dynamics (including both convective-scale and meso-scale), and thermodynamics; and (2) validate and improve parameterization of cirrus clouds in weather/global models. The satellite retrievals take a great effort to use in model validation/evaluation, and the derived cloud information will be very useful for cloud data assimilation. Examples of issues to be examined are:

- What are the physical processes that maintain tropical cirrus cloud systems?
- What is the relationship between atmospheric dynamics and cirrus cloud systems?
- What is the role of tropical cirrus clouds in regulating the upper tropospheric moisture budget?
- How do tropical cirrus clouds affect the column radiation budget?

On 16 July 2002, as a sample case, a relatively isolated convection system and its persistent anvil were sampled extensively during the CRYSTAL-FACE Mission's flights. Figure 3 shows that the model system, indeed, is able to capture the structure of cloud systems with higher model-resolution. Furthermore, it is obvious that the high-resolution model forecast presents much more detailed and accurate indications of the cloud systems. Cloud properties from GOES and model forecast/assimilation compare well, which is shown in the right panel of Fig. 3. The frequencies are computed for the individual cloud system. Comparisons of frequency distributions yield surprisingly good results, and the assimilation-generated properties are more close to those of the satellite retrievals. Some differences are significant in some parameter comparisons. For example, cloud tops are higher and cloud top temperatures are lower and more narrowly distributed when compared to those from the satellite observations. The cloud total water paths have more large values, and the outgoing LW fluxes (e.g., OLR) are lower because the forecast/assimilation cloud tops are too high (Wang et al., 2003). We expect that there would be some improvements if the satellite-derived cloud information is used for data assimilation.

On 13 July 2002, the Mission's flights provided extensive samples of tropopause thin cirrus clouds in the southern Florida region. Optically thin cirrus clouds were present within a few thousand feet of the tropopause throughout the flight. The Cloud Physics Lidar (CPL) on the ER-2 indicated that thin cirrus clouds were measured in the top 1 to 2 km of the tropopause throughout the flight (see Fig. 4). This subvisual tropical tropopause cloud was simulated very well by the cloud-scale NWP model with the realistic 3-D atmospheric fields (Fig. 5). The simulations have good agreement with the lidar measurements shown in Fig. 4. We will continue to focus on investigating the formation, evolution, and radiative properties of the thin cirrus clouds. To our knowledge, this successful simulation is the first attempt of the subvisual thin-cirrus modeling by a NWP model with realistic 3-D meteorological fields.

4. Related Publications

Cloud system analysis/modeling and cloud data assimilation studies with the extensive CRYSTAL-FACE data are still being conducted. The results to date have been documented in the papers listed below.

Publications of D. H. Wang related to CRYSTAL-FACE

Wang, D. –H., P. Minnis, et al., 2002: Real-time High-resolution Forecast Support for CRYSTAL-FACE With Supercomputing Resources at NCCS. *Report to NASA Center for Computational Sciences (NCCS).*

CRYSTAL-FACE – NCCS Points the Way for Cloud Researchers, Article by Michael Mendoza at NASA/GSFC, Published in *NASA/GSFC ESDCD News.*

Wang, D. –H., P. Minnis, et al., 2003a: 4D Data Reanalysis/Assimilation with Satellite, Radar and the Extensive Field Measurements, *CRYSTAL-FACE Science Team Meeting*, Salt Lake City, UT, 24-28 Feb. 2003.

Wang, D. –H., P. Minnis, et al., 2003b: Convection-Anvil and Thin-Cirrus Simulations by a Cloud-Resolving NWP Model: Some Preliminary Results, *CRYSTAL-FACE Science Team Meeting*, Salt Lake City, UT, 24-28 Feb. 2003.

Wang, D. –H., and P. Minnis, 2003c: Cloud-Resolving NWP Modeling of the Deep-Convection-Induced Cirrus during CRYSTAL-FACE, *EGS-AGU-EUG Joint Assembly*, Nice France, 06-11 April 2003.

Wang, D. –H., P. Minnis, et al., 2003d: Comparison of cloud-radiative properties from model prediction and satellite retrievals during CRYSTAL-FACE. *AGU 2003 Fall Meeting*, San Francisco, CA, 8-12 Dec. 2003.

Wang, D. –H., P. Minnis, et al., 2004: Comparison of cloud-radiative properties from regional very-high-resolution modeling and satellite retrievals. *ARM 2004 Science Team Meeting*, Albuquerque, NM, 22-26 March 2004.

David Star, Ruei-Fong Lin, Andrew Lare, Belay Demoz, Thomas Rickenbach, Donghai Wang, Lihua Li, G. Thomas Arnold, and Yansen Wang: Mesoscale Simulations of CRYSTAL-FACE 23 July 2002 Case, 1*4 International Conference on Clouds and Precipitation,* Bologna, Italy, July 14-18, 2004.

Xueref, I, and co-authors, 2004: Coupling a receptor-oriented framework for tracer distributions with a cloud resolving model to study transport in deep convective clouds: application to the CRYSTAL-FACE campaign, Submitted to *J. Geophys. Res.*

Fridlind, A.M., A. S. Ackerman, E. J. Jensen, A. J. Heymsfield, M. R. Poellot, D. E. Stevens, D.–H. Wang, L. M. Miloshevich, D. Baumgardner, R. P. Lawson, J. C. Wilson, R. C. Flagan, J. H. Seinfeld, H. H. Jonsson, T. M. VanReken, V. Varutbangkul, T. A. Rissman, 2004: Evidence for the Predominance of Mid-Tropospheric Aerosols as Subtropical Anvil Cloud Nuclei, *Science*, **304**, 718-722.

Wang, D. –H., P. Minnis, et al.: Convection-Anvil Cloud System Simulations and Comparison with Satellite Retrievals (in preparation).

Wang, D. –H., P. Minnis, et al.: Modeling Relationships between SST, Convection, and Precipitation (in preparation).

FIGURE LIST

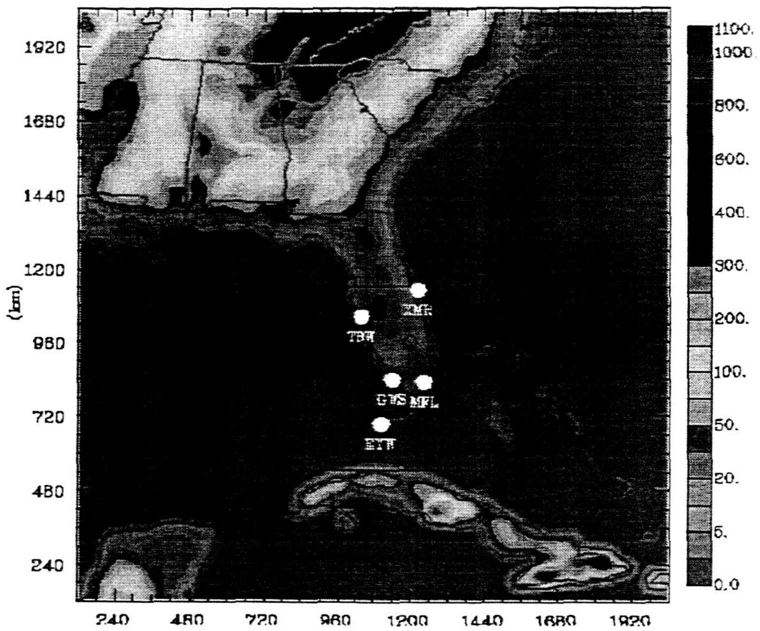
Fig. 1. Model terrain and the two nested grid domains, with 15 km (outer domain) and 3 km (inner domain) grid-size over the CRYSTAL-FACE area.

Fig. 2. The web-based forecast product display system.

Fig. 3. Left: Model-predicted/assimilated cloud field (upper) and the corresponding radar and satellite observations (lower). Right: The frequency distribution histogram of ice-water path (upper), cloud-top height (middle), and outgoing LW fluxes (lower) for satellite retrieval (black), forecast-generated (red) and assimilation-generated (green).

Fig. 4. ER-2 flight tracks on July 13, 2002 and the Cloud Physics Lidar (CPL) measurements (right panel, unpublished results courtesy Matthew McGill at GSFC).

Fig. 5. Left: Model-predicted 3D cloud at 1630 UTC (upper) and 2100 UTC (lower), July 13, 2002. Right: The south-north cross-sections of ice water and temperature (upper), as well as the relative humidity (lower) at 1630 UTC 13 July 2002.



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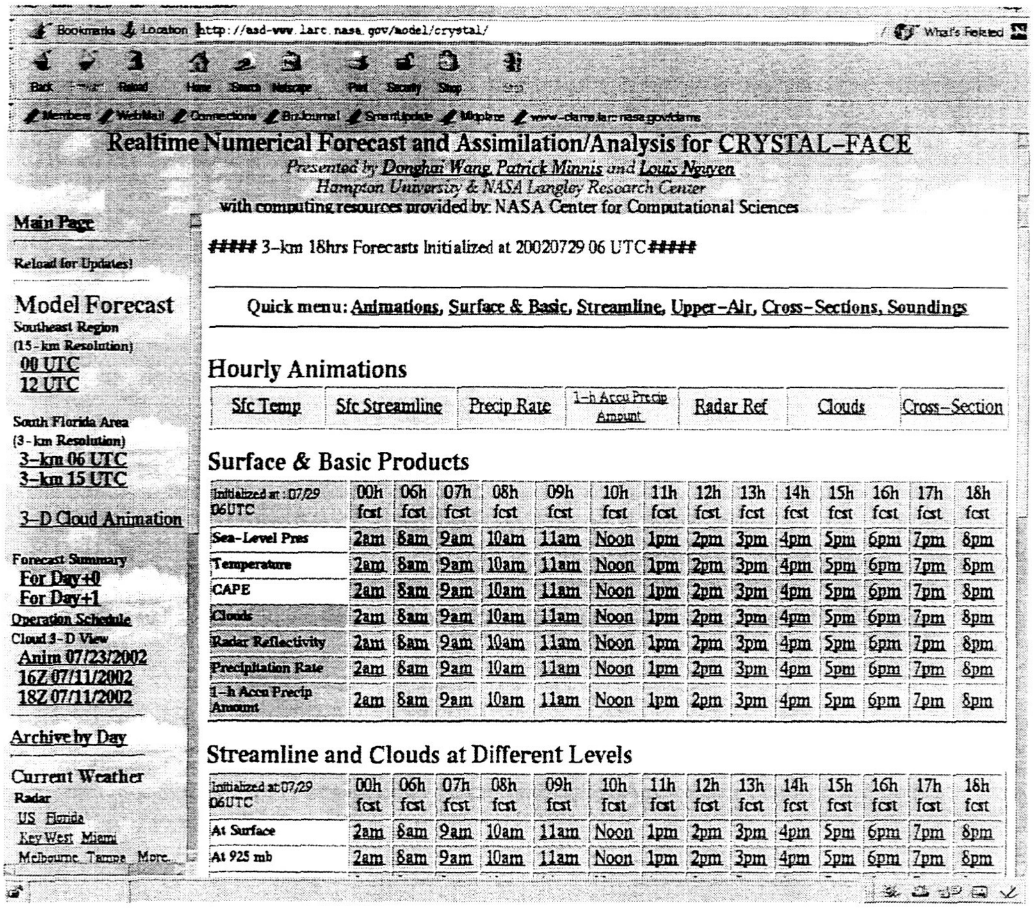

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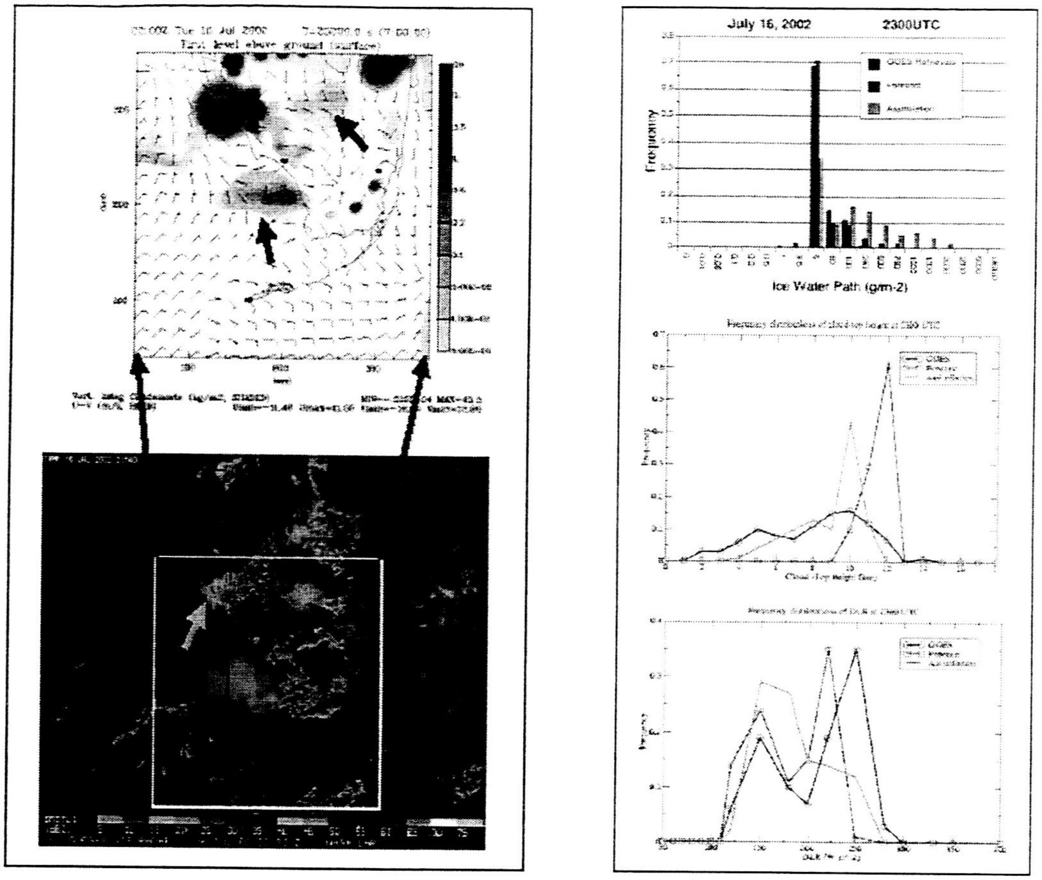

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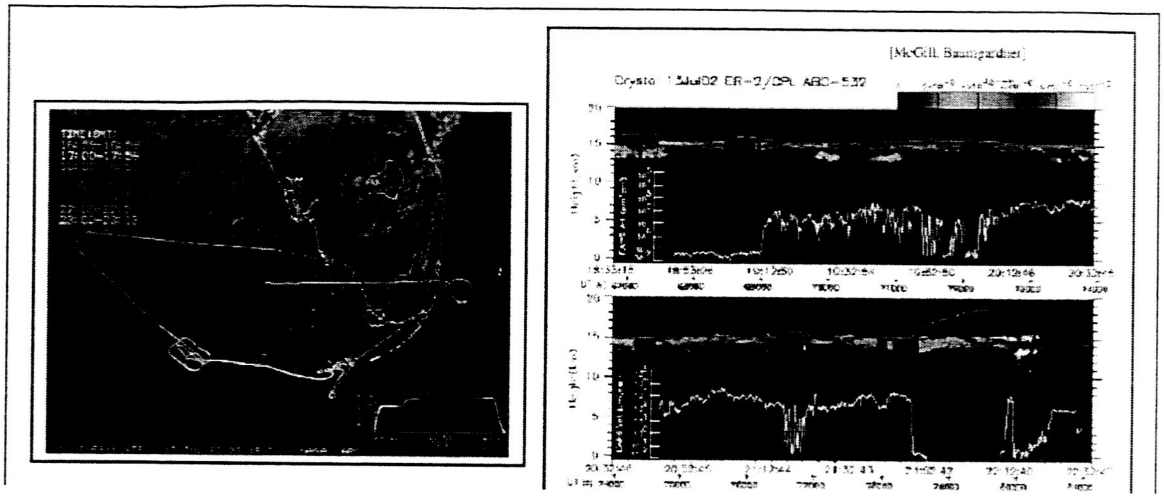

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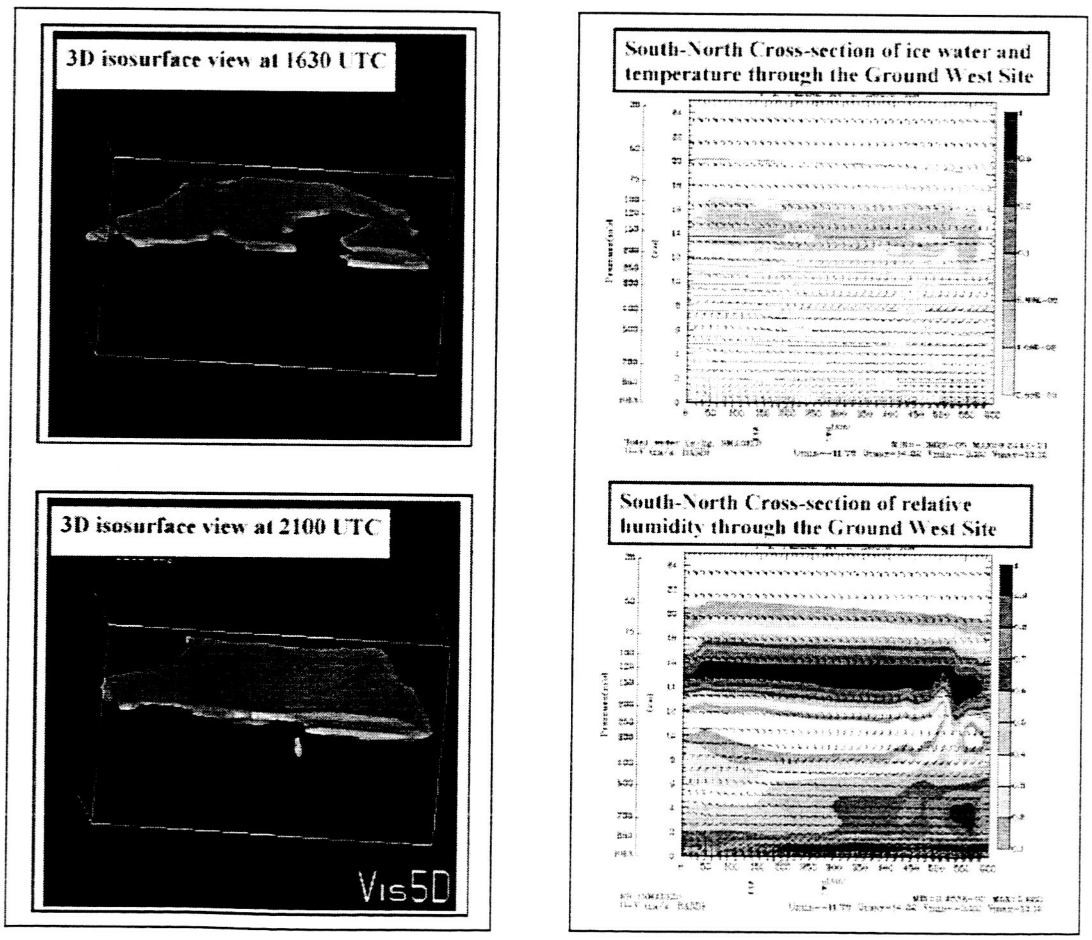

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